Flexible Electronics Using Ion Implantation to Adhere Polymer Substrate to Single Crystal Silicon Substrate

Statement Regarding Federally-Sponsored Research or Development

[0001] The U.S. Government has a paid-up license in the present invention and the right in limited circumstances to require the patent owner to license others on fair and reasonable terms as provided by the terms of Department of Defense Contract No. DMR-0308127.

Claim to Domestic Priority

[0002] The present non-provisional patent application claims priority to provisional application serial no. 60/523,022 entitled "Enhanced Adhesion of Organic Layer/Film/Substrate Surfaces to Inorganic Layer/Film/Substrate Surfaces", filed on November 17, 2003. The present non-provisional patent application further claims priority to provisional application serial no. 60/524,009 entitled "Adhesion between Silicon and Polymer by Implanting Hydrogen Ions through Polymer into Silicon", filed on November 21, 2003. The present non-provisional patent application further claims priority to provisional application serial no. 60/524,010 entitled "Adhesion between Silicon and Polymer by Implanting Hydrogen Ions through Polymer into Silicon", filed on November 21, 2003.

Field of the Invention

[0003] The present invention relates in general to flexible electronics and, more particularly, to a flexible

display or electronic device using ion implantation to bond a flexible substrate to single crystal silicon substrate.

Background of the Invention

[0004] Flat panel displays are used in many applications to visually present data and images. Flat panel displays have a thin profile and provide high resolution for uses such as computer monitors and television screens. The liquid crystal display (LCD) is one type of flat panel display. The LCD uses a silicon on glass substrate. The active semiconductor-based pixels are formed on the silicon substrate. The glass substrate is conducive to high temperatures which are commonly used in many semiconductor manufacturing processes.

[0005] While LCDs have been around for some time and are generally preferred over CRT-type displays, such glass-based flat panel displays have disadvantages as well. The glass component is known to be heavy and brittle. LCDs are known to crack and are susceptible to damage. Moreover, glass displays are generally not useable in applications requiring flexibility for the display.

[0006] As new applications arise, the need for flexible flat panel displays continues to grow. Prior art flexible flat panel displays use thin film transistors (TFT) formed on amorphous silicon layers or polycrystalline silicon layers. Unfortunately, amorphous silicon and polycrystalline silicon TFTs exhibit low carrier mobility and high off-state current leakage, which reduces performance and increases power consumption. The resolution decreases and flickering may be observed in flat panel displays using TFTs formed on low carrier mobility polycrystalline silicon.

[0007] A similar problem is found in electronic devices

using polycrystalline silicon. The lower carrier mobility associated with polycrystalline type substrates reduces the performance of the electronic device.

[0008] On the other hand, single crystalline silicon is known to have greater carrier mobility. The higher carrier mobility in the presence of an electrostatic field, as found in single crystalline silicon, provides better performance for flat panel displays and electronic devices. However, single crystalline silicon typically involves higher temperature semiconductor processes. These high temperatures are incompatible with polymer and other flexible amorphous substrates.

[0009] A need exists for a flat panel display or electronic device using single crystalline silicon on a flexible substrate.

Summary of the Invention

[0010] In one embodiment, the present invention is a flat panel display, comprising a flexible substrate. A single crystalline silicon substrate is disposed adjacent to the flexible substrate. The flexible substrate is bonded to the single crystalline substrate using an ion implantation process. A plurality of semiconductor devices are formed on the single crystalline silicon substrate.

[0011] In another embodiment, the present invention is an electronic device comprising a flexible substrate. A single crystalline silicon substrate is disposed adjacent to the flexible substrate. The flexible substrate is bonded to the single crystalline substrate using an ion implantation process. A plurality of active semiconductor devices are formed on the single crystalline silicon substrate.

[0012] In another embodiment, the present invention is an

electronic apparatus comprising a flexible substrate. A single crystalline silicon substrate is disposed adjacent to the flexible substrate. The flexible substrate is bonded to the single crystalline substrate using an ion implantation process. A plurality of semiconductor devices are formed on the single crystalline silicon substrate.

[0013] In another embodiment, the present invention is a method of forming an electronic apparatus comprising providing a flexible substrate, providing a single crystalline silicon substrate disposed adjacent to the flexible substrate, wherein the flexible substrate is bonded to the single crystalline substrate using an ion implantation process, and providing a plurality of semiconductor devices formed on the single crystalline silicon substrate.

Brief Description of the Drawings

[0014] FIG. 1 illustrates a flexible panel display receiving data;

FIG. 2 illustrates a flexible substrate disposed adjacent to a single crystalline silicon substrate;

FIG. 3 illustrates an ion implantation source implanting ions through the flexible substrate to the interface between the flexible and silicon substrates; and

FIG. 4 illustrates ion implantation through polymer layer into silicon substrate.

Detailed Description of the Drawings

[0015] The present invention is described in one or more embodiments in the following description with reference to the Figures, in which like numerals represent the same or similar elements. While the invention is described in terms

of the best mode for achieving the invention's objectives, it will be appreciated by those skilled in the art that it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and their equivalents as supported by the following disclosure and drawings.

[0016] A flexible flat panel display 10, such as shown in FIG. 1, has a myriad of uses in the electronics and display markets. For example, the flexible flat panel display 10 can be used for an electronic paper. Information can be downloaded from data source 12, e.g., personal computer, wireless link, or satellite link, into the electronic paper memory for viewing on the display screen, as shown in FIG. 1. Because the flat panel display is flexible, the electronic paper can be rolled up after use and stored in a convenient location. Other commercial uses include portable military displays on clothing, displays implanted in living tissue of humans and animals, and displays that must conform to irregular or non-flat surfaces. The flexible flat panel display 10 can mold or conform to most any non-flat, organic or inorganic surface.

[0017] In another embodiment, element 10 may be a flexible electronic device. The flexible electronic device may be an integrated circuit, or a flexible print circuit board with integrated circuits mounted thereon. The flexible electronic device can be used in diagnostic equipment, small and odd-shaped enclosures, and any application requiring a flexible form factor. The flexible electronic device also has uses in military applications similar to flat panel display 10.

[0018] In the fabrication of flat panel displays and electronic devices, it is desirable to use a single crystalline silicon substrate because of its higher carrier

mobility properties in the presence of an electrostatic field. A flat panel display or electronic device made with single crystalline silicon substrate provides improved performance and response time by way of higher carrier mobility and uniform threshold voltages.

[0019] In FIG. 2, a single crystalline silicon substrate 20 is disposed on, and in contact with, flexible substrate 22. Flexible substrate 22 may be made with a flexible material such as polymer, paper, plastic, flexible glass, stainless steel, or other flexible inorganic base. Flexible substrate 22 provides a strong, yet flexible mechanical support structure for silicon substrate 20. The flexible substrate 22 is what allows the flat panel display or electronic device to bend and flex in the above mentioned applications. Semiconductor devices 24 are formed on silicon substrate 20. The semiconductor devices 24 include active and passive components necessary to perform the desired electrical function. In another embodiment, the semiconductor devices 24 may be TFTs, as well as other active and passive components, in flexible flat panel display or flexible electronic device 10.

[0020] To be useful in flexible displays or electronic devices, single crystalline silicon substrate 20 must be strongly bonded to flexible substrate 22. An ion implantation process is used to form the strong adhesive interface or bond between silicon substrate 20 and flexible substrate 22. The ion implantation induces a mixing process at the interface to change the composition and chemical bonding state between the substrates. The mixing process makes for a strong adhesion between silicon substrate 20 and flexible substrate 22.

[0021] Turning to FIG. 3, an ion implantation source 30 is positioned on the back side, oriented in the direction toward

flexible substrate 22. The implantation source 30 may use hydrogen, helium, xenon, krypton, or other inert, noble gases as its source of ions. Once the flexible substrate 22 is disposed adjacent to, and in contact with, silicon substrate 20, the implantation source 30 radiates on ion beam, e.g., H^+ or He^+, through flexible substrate 22 and into silicon substrate 20.

[0022] In one embodiment, the ion implantation penetrates deep into silicon substrate 20 to induce an ion cut. The ion cut involves formation of H_2 gas bubbles in high internal pressure which causes a cleavage within the silicon. The ion cut facilitates separation of a thin slice of the silicon substrate.

[0023] The penetration depth of the ion beam is a function of beam particle energy. By adjusting the ion beam energy level, the ion implantation process can induce an energy loss at the interface between silicon substrate 20 and flexible substrate 22. The energy loss cause ions to be deposited at the substrate interface by ion mixing to induce adhesion between the materials. The single crystalline silicon substrate 20 bonds to the flexible substrate 22 in response to the ion beam having the appropriate energy level to induce the ion mixing at the interface between silicon substrate 20 and flexible substrate 22.

[0024] In one embodiment, the ion cut process deposits ions deeper in the silicon substrate, while the ion mixing process at the silicon and flexible substrate interface is performed in different ion implantation steps. One ion beam energy level performs the ion cut, and a second ion beam energy level causes the ion mixing at the substrate interface. Alternatively, the ion implantation deeper in the silicon substrate for the ion cut operation and the ion mixing at the silicon and flexible substrate interface is

performed in the same ion implantation step. FIG. 4 shows hydrogen ions being implanted through polymer substrate to the silicon substrate. The ion mixing at the boundary between flexible substrate 22 and single crystalline substrate 20 induces bonding between the two layers.

[0025] While one or more embodiments of the present invention have been illustrated in detail, the skilled artisan will appreciate that modifications and adaptations to those embodiments may be made without departing from the scope of the present invention as set forth in the following claims.